



# RESEARCH MEMORANDUM

CLASSIFICATION CHANGED TO DECLASSIFIED  
EFFECTIVE JUNE 12, 1965  
AUTHORITY NASA CCN-4 BY J. J. CARRE

AN INVESTIGATION AT LOW SPEED OF THE SPIN

INSTABILITY OF MORTAR-SHELL TAILS

By John D. Bird and Jacob H. Lichtenstein

Langley Aeronautical Laboratory  
Langley Field, Va.

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NATIONAL ADVISORY COMMITTEE  
FOR AERONAUTICS

WASHINGTON

June 19, 1957

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REF ID: A11710

## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

## RESEARCH MEMORANDUM

## AN INVESTIGATION AT LOW SPEED OF THE SPIN

## INSTABILITY OF MORTAR-SHELL TAILS

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## SUMMARY

An investigation was made in the Langley stability tunnel to study the influence of number of fins, fin shrouding, and fin aspect ratio on the spin instability of mortar-shell tail surfaces. It was found that the 12-fin tails tested spun less rapidly throughout the angle-of-yaw range than did the 6-fin tails and that fin shrouding reduced the spin encountered by a large amount.

## INTRODUCTION

An examination of various features of the short-range phenomenon of mortar shells (reduced range of an occasional shell) has shown that an instability of spin (negative roll damping about the body axis) can result in short-range performance if there is a sufficiently large disturbance in yaw when the shell is launched (refs. 1 and 2). Reference 1 is a study of various causes of short-range performance, and reference 2 demonstrates that short-range performance may be obtained as a result of a spin instability caused by a lift hysteresis of the tail surfaces of a mortar shell. The lift hysteresis of concern herein is associated with stall conditions. A discussion of this phenomenon in connection with the action of a child's toy known as a "bullroarer" is given in reference 3. Mortar shells are not usually designed to spin and, hence, have no cant to their fins. The mechanism by which the short-range performance of references 1 and 2 occurs involves several interrelated phenomena which act together to produce a large-amplitude precessional motion. The increased drag in this motion is sufficient to cause an appreciable shortening of range. The precessional nature of the motion results from the combined effect of the aerodynamic stability and the angular momentum associated with spin of the shell. This phenomenon is, of course, nothing more than the gyroscopic effect and is similar to the precessional motion of a top about the vertical. The persistence of the angular momentum about the longitudinal axis of the shell is insured by the postulated instability

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of spin, and the persistence of the precessional motion is insured by a destabilizing magnus moment which arises as a result of the spin and which acts to overcome the aerodynamic damping of the tail surfaces of the shell. This magnus moment acts about the axis normal to the nodal axis (fig. 1) and is a nonlinear function which, for the aerodynamic forms of interest herein, increases rapidly with angle of yaw and varies almost directly with rate of spin. For small disturbances in yaw, the magnus moment is insufficient to overcome the aerodynamic damping of the tail surfaces, and the shell is stable. For large disturbances in yaw, however, the magnus moment exceeds the aerodynamic damping of the tail surfaces, and the model precesses at increasing yaw until an equilibrium between tail damping and magnus moment is reached at a large angle of yaw where the magnus moment has begun to increase less rapidly with yaw than the tail damping.

The purpose of the present investigation was to determine the spin instability of several forms of mortar-shell tail surfaces in more detail than was employed in reference 2 with a view to establishing quantitatively the influence of number of fins, aspect ratio of fins, and fin shrouding on spin instability for a range of yaw angles. For this purpose, mortar-shell tail assemblies mounted on ball bearings were extended from the tunnel floor in a downstream direction at various angles and the tendencies of the tail assemblies to spin were observed.

## NOMENCLATURE

The results are presented relative to the sketch shown in figure 1 in which spin and positive angular displacement in yaw are indicated by arrows. Certain terms employed in the text are defined as follows:

Spin - Rotational motion of tail surface about shell longitudinal axis  
(clockwise spin defined as viewed from rear)

Angle of yaw - Angle between shell longitudinal axis and wind direction  
Angle of precession- Angular position of plane defined by shell longi-

right of precession. Angular position of plane defined by shear longitudinal axis and wind direction measured in plane perpendicular to wind direction from an arbitrary reference position (fig. 1)

Nodal axis- Axis about which angle of yaw is measured.

## APPARATUS AND MODELS

The equipment employed in these tests consisted of several mortar-shell tail surfaces, a ball-bearing-equipped support post suitable for inclining the model at various angles to the wind stream, a brake for restraining the rotation of the model, and a Strobotac for observing

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the spin rate of the tail assemblies. Figure 2 is a sketch of the test rig and figure 3 shows the rig mounted in the test section of the Langley stability tunnel. The basic 12-fin model (tail 1) was constructed of mahogany (fig. 3) and had integral bearing mounts. The remainder of the models employed in these tests (figs. 4, 5, and 6) were constructed of balsa, fiber glass, and a plastic material. These models were made as shown in figure 6 and were attached to the rear of the mounting post which was free to spin. Pertinent dimensions of the various models are given in figure 7. Tail 1 had an aspect ratio of 2.0, based on tail span and mean chord. Tails 2, 3, and 6 had aspect ratios of about 1.8 on the same basis, and tails 4 and 5 had aspect ratios of about 0.9 and 2.9, respectively. Plastic tape was wrapped around the fins on tail 2 to make tail 3. All the tails were constructed with no cant to the fins.

The support post and brake are shown in figures 2 and 3. A 1/4-inch-diameter shaft extended from the support post and supported a section of the rear of the post on ball bearings. The models with the exception of tail 1 were mounted on this section of the post. The brake had a leather shoe to obtain friction and was actuated from outside the tunnel by a string.

## TESTS

The spin rates of the tail assemblies were observed at various angles of yaw to the wind stream. Within the limits of this investigation the results appeared to be reproducible. In some cases the models rotated either clockwise or counterclockwise on release. In these cases, spin rates were recorded for both directions. In all cases four or more trials were made to determine the direction in which the model would spin. Note was taken of any peculiarities of behavior during the tests. All tests were conducted at a dynamic pressure of 25 pounds per square foot. No effort was made to balance the models accurately about their spin axes inasmuch as they were symmetrically constructed and light in weight.

## RESULTS AND DISCUSSION

### Presentation of Results

A list of all tests conducted and the data obtained is given in tables I to VI. These data are plotted in figures 8, 9, and 10 to show the effects of number of fins, fin shroud, and tail aspect ratio on the spin characteristics of the tails. The direction of spin at each data point is indicated on the plots by an arrow (clockwise rotation is

defined as viewed from the rear). The lines faired through the data are simply to indicate the general trend of the results.

#### Effect of Number of Fins

The 6-fin tail (tail 2) shows a much greater spin rate throughout the angle-of-yaw range than the 12-fin tail (tail 1). (See fig. 8.) This difference probably explains why the 12-fin tail did not sustain a large-amplitude whirling motion of the mortar shell in the experiments of reference 2. In the case of free-flight launching where the ball-bearing friction in the rig of reference 2 would not be present, it is likely that the small spin rate of the 12-fin tail could cause short-range behavior. It should be noted that the 6-fin tail (tail 2) shows different spin rates for clockwise and counterclockwise motions. This characteristic is likely to be caused by an aerodynamic or configurational asymmetry.

An interesting point is associated with the spin rate recorded for the 12-fin tail (tail 1) at  $50^\circ$  yaw. In this case, only clockwise spin started on release of the brake, yet at the angles on either side ( $45^\circ$  and  $55^\circ$ ) only counterclockwise spin started. Similar results may exist at other points in the data. A careful investigation of this effect was not made. This effect may be associated with the wake of the support post and is indicative of a change in wake asymmetry as occurs in the two-dimensional case during the discharge of a Karman street. Reference 4 shows that asymmetrical wakes can exist for slender pointed bodies and that these asymmetrical wakes are sensitive to angle of attack and small turbulence rings.

#### Effects of Shrouds

The 12-fin-tail model with the ring shroud (tail 6) spun at a much lower rate than the 12-fin-tail model without the shroud (fig. 9). For tail 6, spin was obtained at only two angles of attack and, in these cases, at only a very low rate. The ring-shroud tail should eliminate the possibility of short-range performance because of its low degree of spin instability and large tail contribution to the damping in pitch of the model. This latter effect comes from increased tail effectiveness. A ring-shroud tail without fins should have no tendency to spin, of course. Adding a shroud of plastic tape to the 6-fin tail (tail 2) to make tail 3 greatly reduced the spin rate obtained (figs. 8 and 9) but did not produce a tail as free of spin as tail 6 except for angles of yaw below  $55^\circ$ . Up to  $55^\circ$  yaw, tail 3 showed no spin at all and, for this reason, may be an entirely satisfactory configuration in that extreme angles of yaw may rarely be encountered in actual mortar-shell firings.

## Effect of Aspect Ratio

Two 6-fin tails of large area (about twice that of tail 2) having aspect ratios of 0.9 (tail 4) and 2.9 (tail 5) were tested to determine the influence of aspect ratio on spin instability. The high-aspect-ratio tail had a much lower spin rate than the low-aspect-ratio tail, but an appreciable spin was obtained for even the high-aspect-ratio tail (fig. 10). No shroud was present in either of these models, of course. The high-aspect-ratio tail because of its large lift effectiveness, and as a result large directional stability and yaw damping, may be a satisfactory mortar-shell tail even with the degree of spin encountered. Reference 2 indicates that this configuration did not show short-range performance for the conditions of those tests.

An interesting point in this respect arises in conjunction with tail 4. Reference 2 shows no short-range performance for this tail assembly, and in fact little tendency toward spin instability, yet a large spin rate was measured throughout the angle-of-yaw range in these tests. It is expected that interference from the front portion of the model and the increased damping and directional stability associated with the large size of this tail were important factors in eliminating the short-range performance in this case.

## CONCLUSIONS

An investigation at low speed of the spin instability of several mortar-shell tails in the Langley stability tunnel indicates the following conclusions:

1. The 12-fin tail tested encountered much less spin throughout the angle-of-yaw range to 85° than the corresponding size 6-fin tail tested.
2. Shrouded 12-fin and 6-fin tails had considerably less spin than unshrouded tails.
3. A 6-fin tail of aspect ratio 2.9 encountered much less spin than a 6-fin tail of aspect ratio 0.9 which had about the same area.

Langley Aeronautical Laboratory,  
National Advisory Committee for Aeronautics,  
Langley Field, Va., April 19, 1957.

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1. Zaroodny, Serge J.: On the Mechanism of Dispersion and Short Ranges of Mortar Fire. With an Appendix on an Alternate Solution of the Equations of Motion of a Yawing Projectile. Rep. No. 668, Ballistic Res. Labs., Aberdeen Proving Ground, Apr. 7, 1948.
2. Bird, John D., and Lichtenstein, Jacob H.: An Investigation of a Source of Short-Round Behavior of Mortar Shells. NACA RM L56G20a, 1956.
3. Den Hartog, J. P.: Mechanical Vibrations. Third ed., McGraw-Hill Book Co., Inc., 1947, pp. 375-377.
4. Letko, William: A Low-Speed Experimental Study of the Directional Characteristics of a Sharp-Nosed Fuselage Through a Large Angle-of-Attack Range at Zero Angle of Sideslip. NACA TN 2911, 1953.

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TABLE I.- TEST DATA FOR TAIL 1 (12 fins)

Angle of yaw, deg	Remarks	Spin rate, rpm (see fig. 2)	
		Counterclockwise	Clockwise
85	Oscillated but did not start spinning	0	0
80	Oscillated but did not start spinning	0	0
75	Started in either direction Spun one way, then stopped, and spun in other direction	About 80 to 90	About 80 to 90
70	-----do-----	About 80 to 90	About 80 to 90
65	Started spinning counterclockwise	370	Did not start
60	Started spinning counterclockwise	370	Do
55	Started spinning counterclockwise	340	Do
50	Started spinning clockwise	Did not start	460
45	Started spinning counterclockwise	300 to 470	Did not start
40	Started spinning counterclockwise	470	Do
35	Did not start spinning; stopped spinning when angle was approached from larger yaw angles	0	0
30	Oscillated slightly but did not spin	0	0

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TABLE II.- TEST DATA FOR TAIL 2 (6 fins)

Angle of yaw, deg	Remarks	Spin rate, rpm (see fig. 2)	
		Counterclockwise	Clockwise
85	Slow to start and spun hesitantly	350	Did not start
80	Started in either direction	300	350
75	Started spinning counterclockwise	1,020	Did not start
	-----do-----	1,380	Do
	-----do-----	1,500	Do
70			
65			
60	Started spinning in either direction	1,570	1,520
	-----do-----	1,260	1,330
	-----do-----	660	1,120
55			
50			
45			
40			
35			
30	Slow to start and spun hesitantly and irregularly	270	320
25	-----do-----	200	Did not start

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TABLE III.- TEST DATA FOR TAIL 3 (6-fin tail with tape shroud)

Angle of yaw, deg	Remarks	Spin rate, rpm (see fig. 2)	
		Counterclockwise	Clockwise
85	Started spinning in either direction	300	350
80	Started spinning in either direction	370	460
75	Started spinning in either direction	500	570
70	Started spinning in either direction	650	710
65	Started spinning in either direction	600	670
60	Started spinning in either direction	600	300
55	Borderline case; spin slowed, stopped, started for several revolutions at a slow rate, stopped, started, oscillated, etc.	0	0
50	Stopped spinning when approached from larger yaw angles (oscillated 1/4 or 1/2 revolution a few times; occasionally made full revolution)	0	0
40	Did not spin; fairly steady	0	0
30	Did not spin; steady	0	0

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TABLE IV. - TEST DATA FOR TAIL 4 (6-fin low-aspect-ratio tail)

Angle of yaw, deg	Remarks	Spin rate, rpm (see fig. 2)	
		Counterclockwise	Clockwise
85	Did not start spinning; stopped if approached from smaller yaw angles	0	0
80	Did not start spinning; continued to spin if started (approached from smaller yaw angles); may do this for either direction but only one direction was investigated	450	Did not start
75	-----do-----	950	Did not start
70	Did not start spinning; continued if started; did not try clockwise	1,260	-----
65	-----do-----	1,500	-----
60	Started spinning in either direction	1,520	1,480
55	Started spinning in either direction	1,120	1,320
50	Started spinning in either direction	880	830
45	Started spinning in either direction	-----	-----
40	Started spinning in either direction	-----	-----
35	Started spinning in either direction	About 200	450
30	Started spinning counter-clockwise	About 145	0
25	Did not start spinning; stopped spinning when approached from larger yaw angle	0	0

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TABLE V.- TEST DATA FOR TAIL 5 (6-fin high-aspect-ratio tail)

Angle of yaw, deg	Remarks	Spin rate, rpm (see fig. 2)	
		Counterclockwise	Clockwise
80	Rotated slowly from 1 to 10 revolutions in one direction and then the other	0	0
70	Started spinning in either direction	480	420
60	Started spinning in either direction	500	480
50	Started spinning in clockwise direction	Did not start	About 300
40	Oscillated; occasionally made one or two revolutions clockwise	0	0
30	Quite steady; oscillated only a few degrees	0	0

TABLE VI.- TEST DATA FOR TAIL 6 (12-fin tail with ring shroud)

Angle of yaw, deg	Remarks	Spin rate, rpm (see fig. 2)	
		Counterclockwise	Clockwise
80	Did not start spinning; oscillated through a small angle	0	0
70	Oscillated through a larger angle than at 80° yaw; spun a few revolutions in either direction and then stopped	0	0
60	Started spinning slowly counterclockwise although slow to start	134	Did not start
50	Did not start spinning	0	0
40	Spun slowly counterclockwise	About 90	Did not start
30	Did not start spinning; even stopped when approached from 40° yaw	0	0

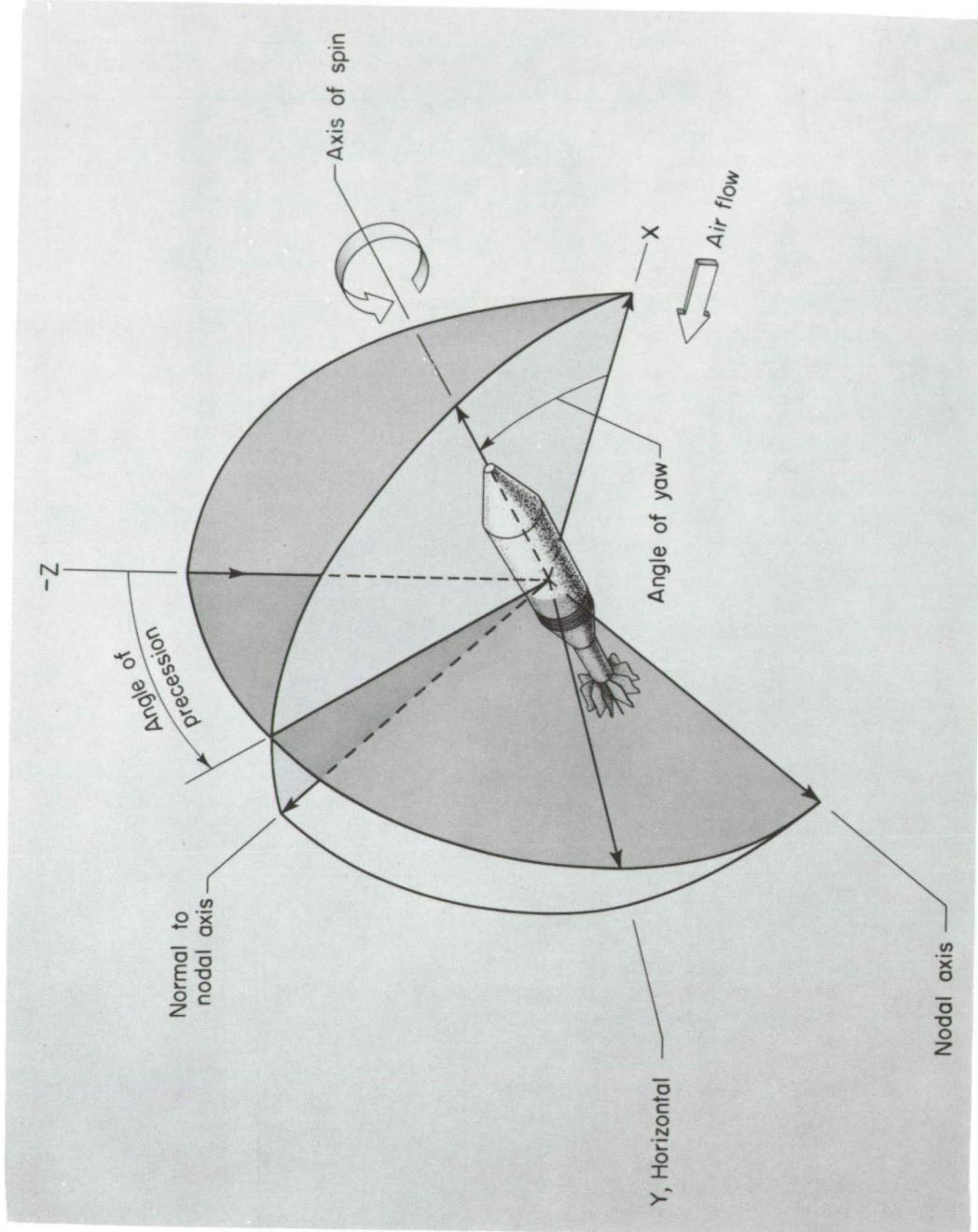


Figure 1.- System of axes used to define spin, yaw, and precession.

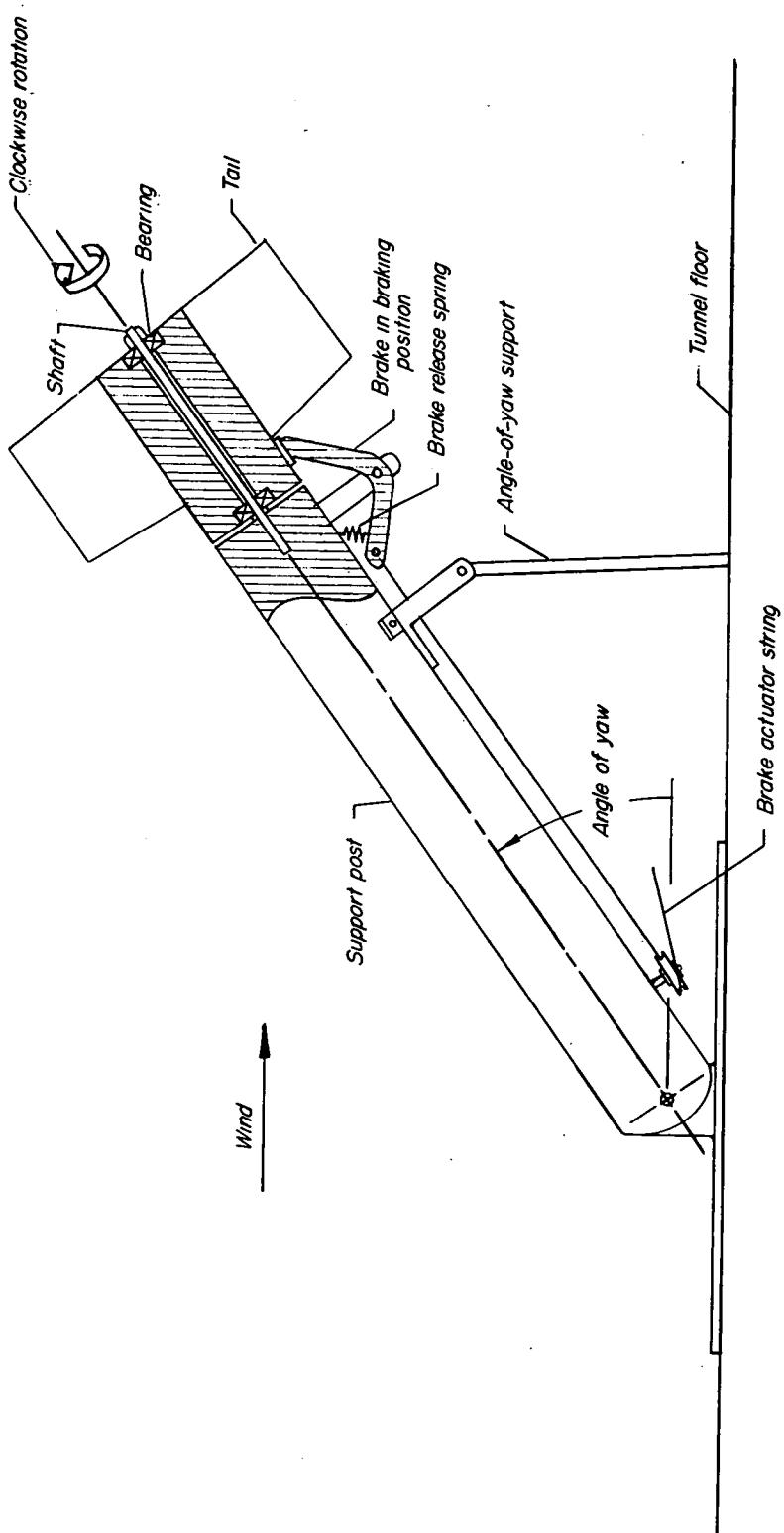


Figure 2.- Sketch of model test rig.

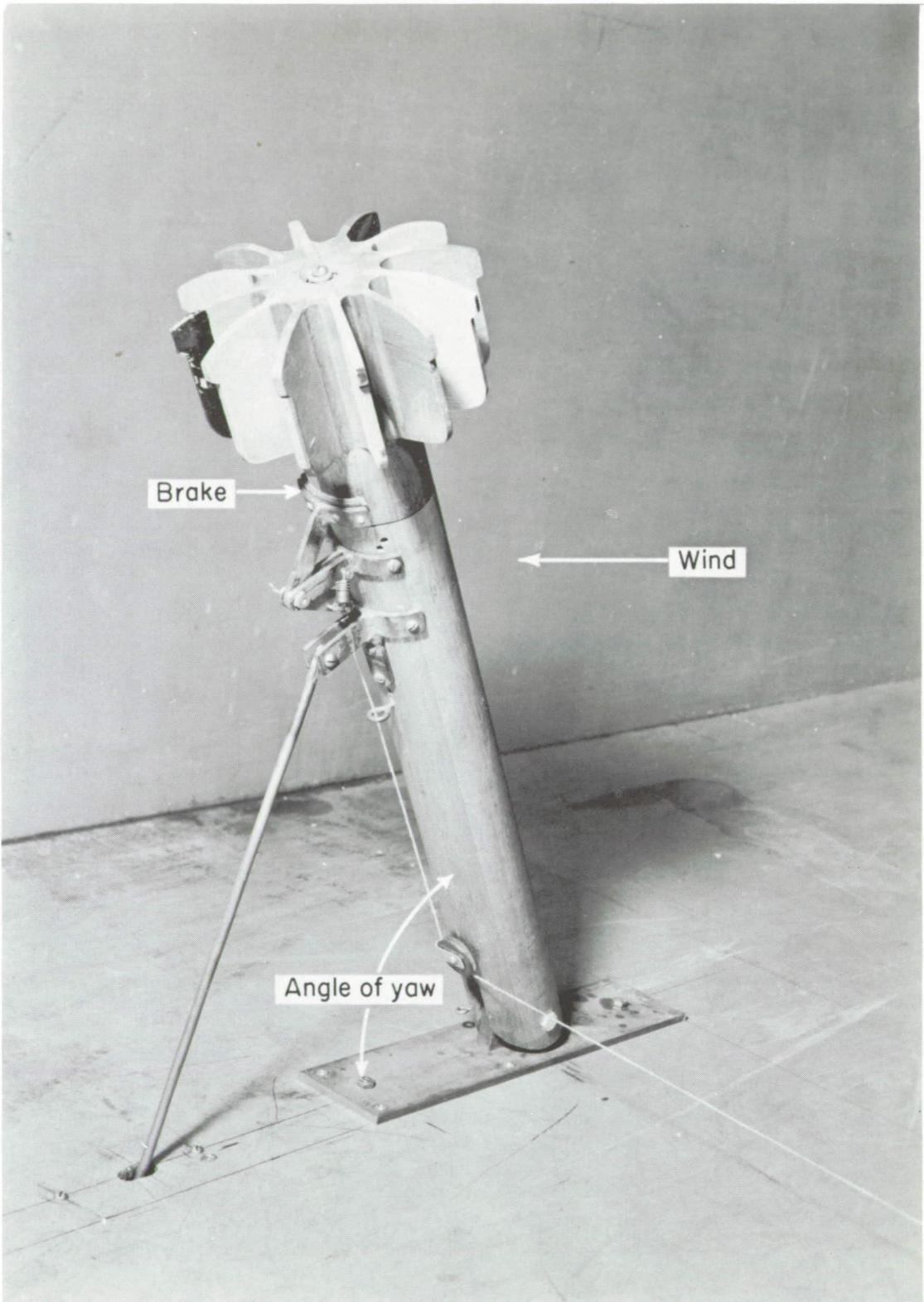


Figure 3.- Tail 1 mounted on test rig.

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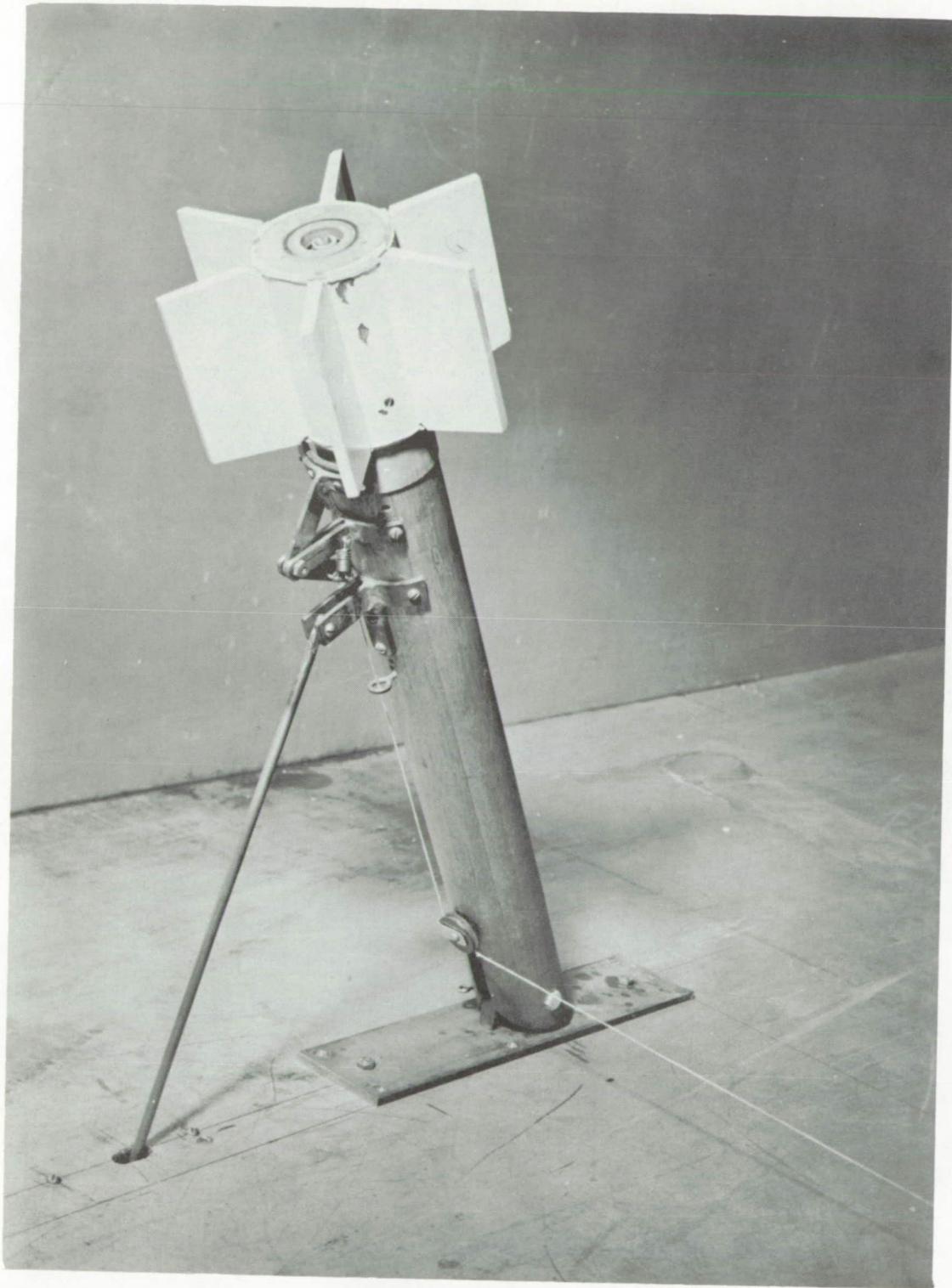


Figure 4.- Tail 2 mounted on test rig.

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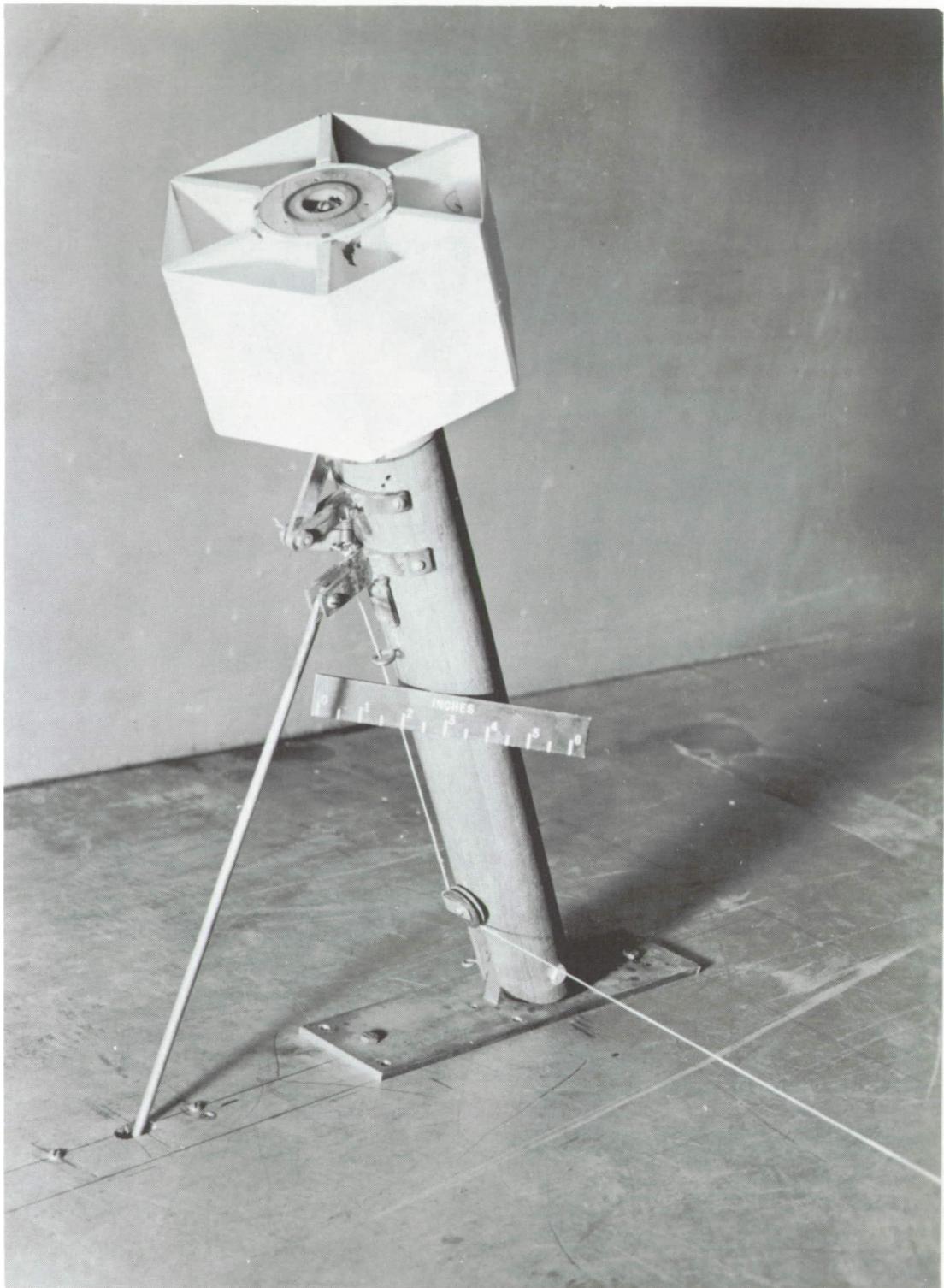


Figure 5.- Tail 3 mounted on test rig.

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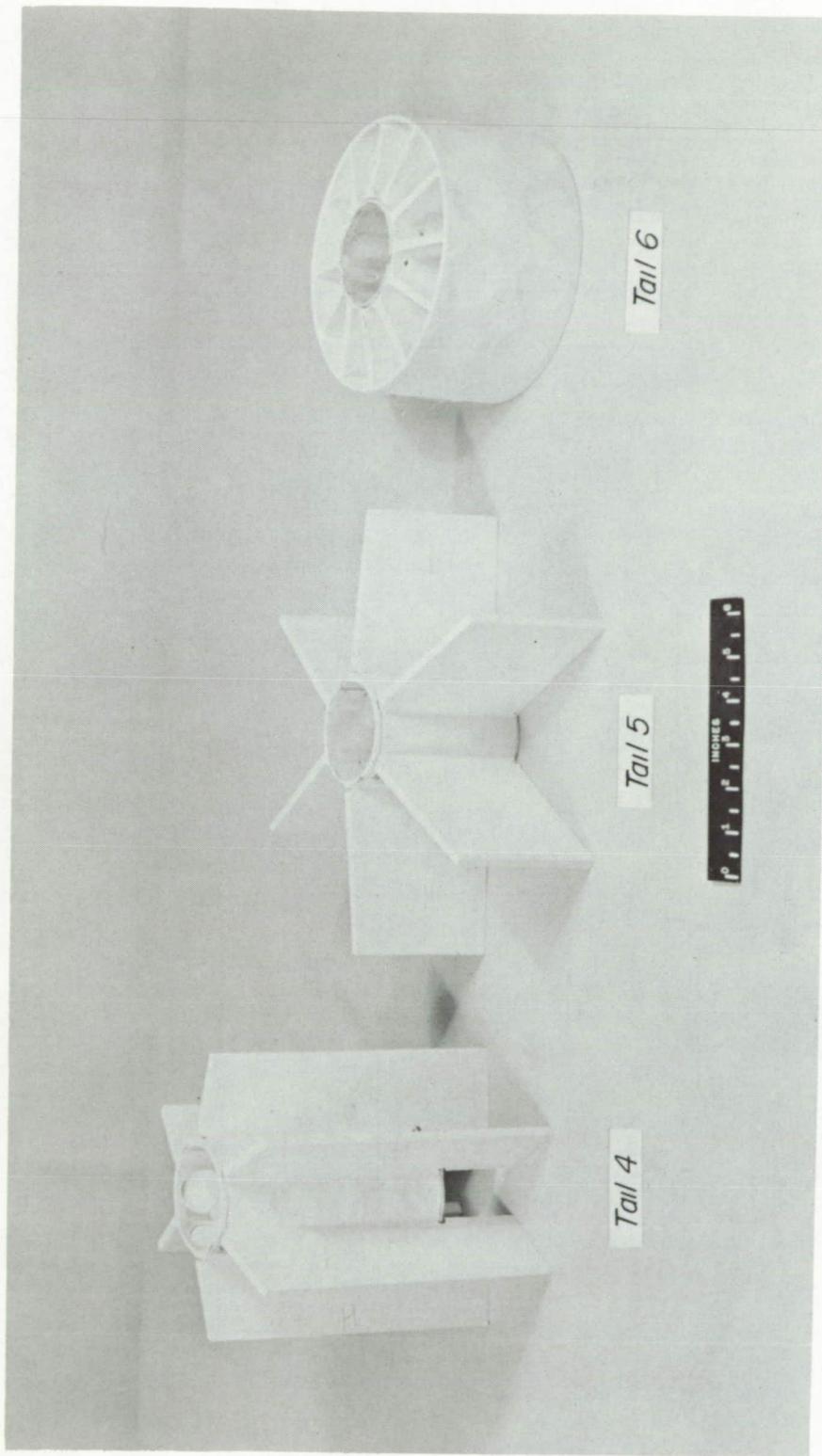


Figure 6.- Tails 4, 5, and 6 unmounted. L-93092.1

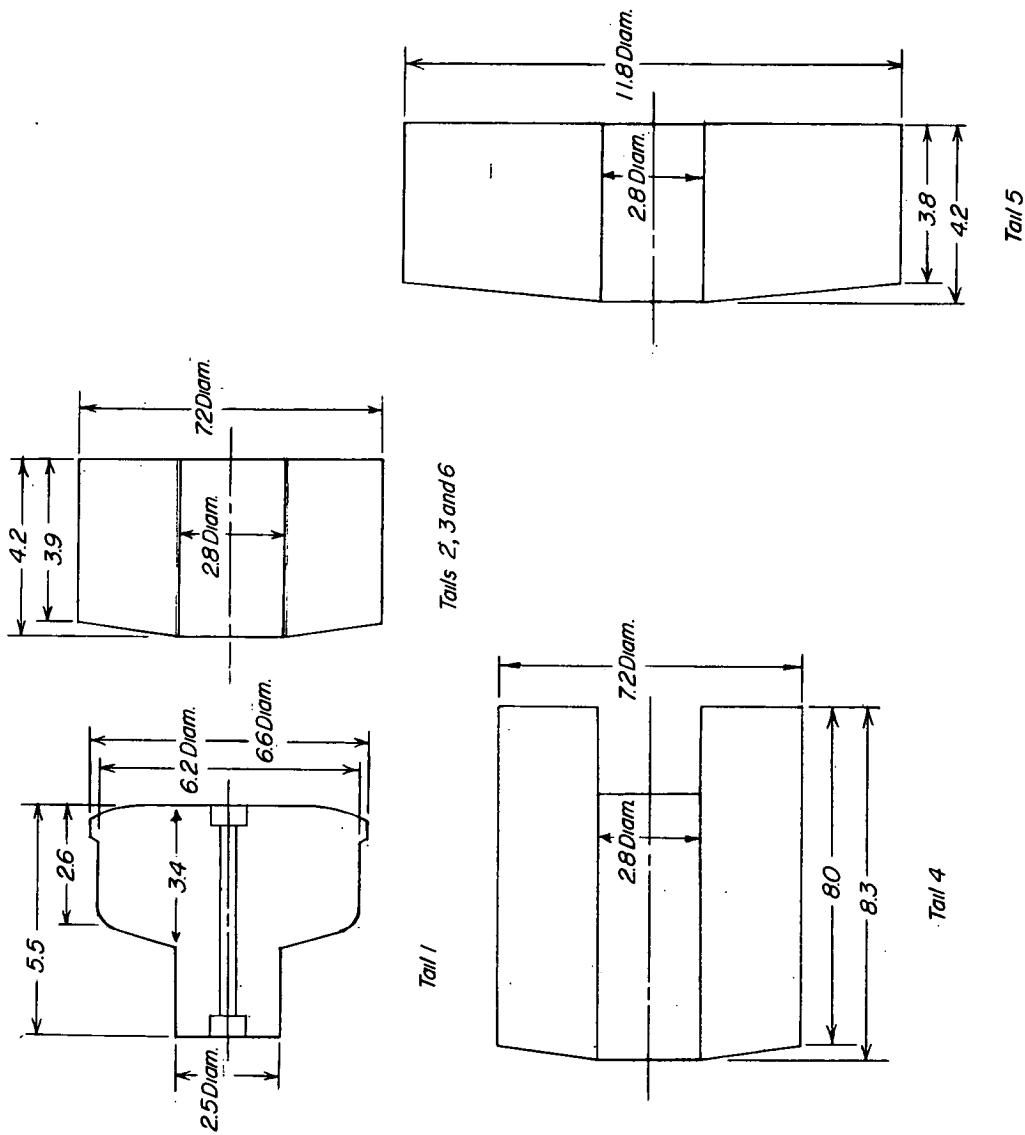


Figure 7.— Dimensions of tails tested. Dimensions are in inches.

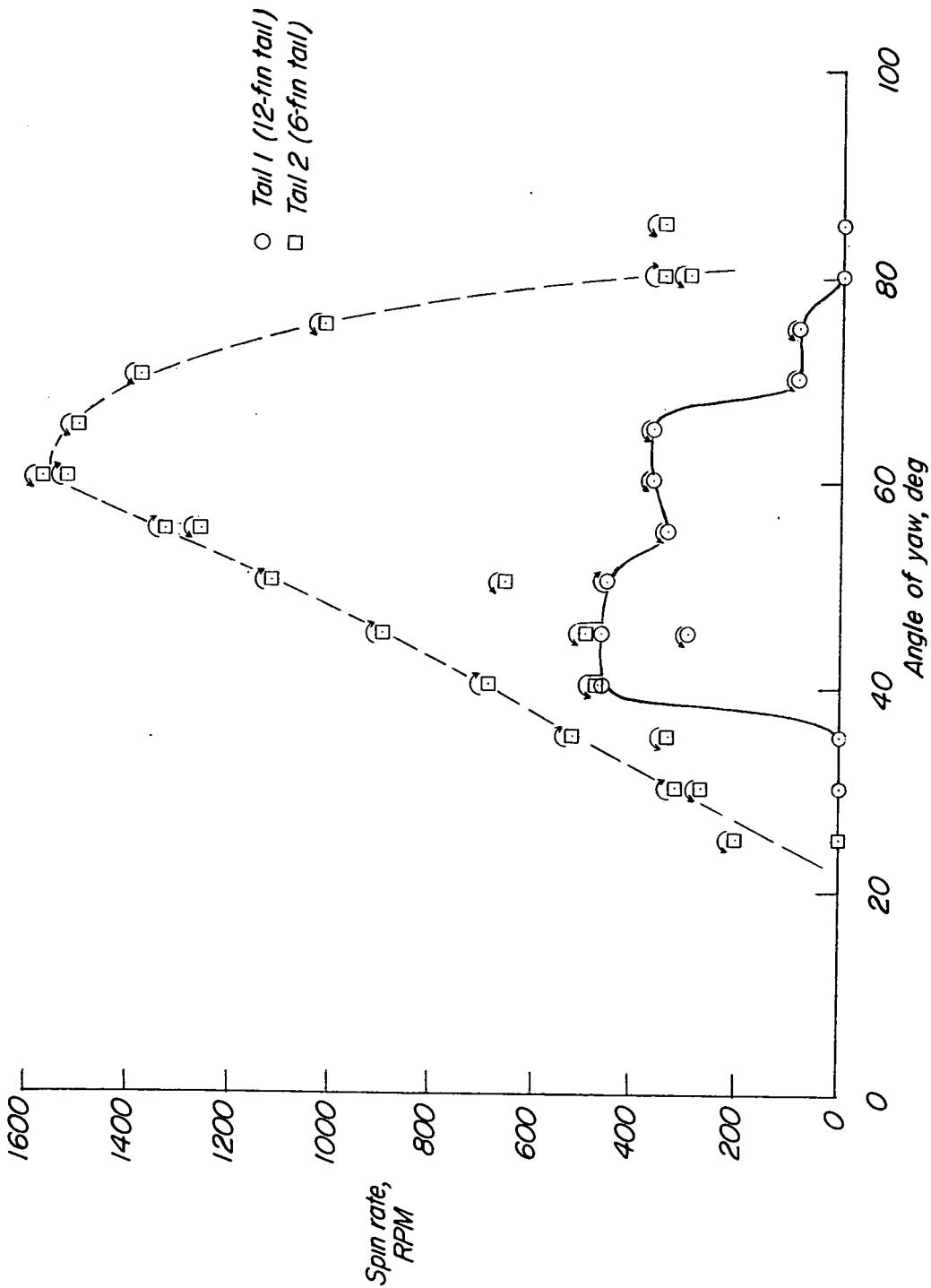


Figure 8.- Effect of number of fins on spin of mortar-shell tails. Direction of spin indicated by arrows (see fig. 2).

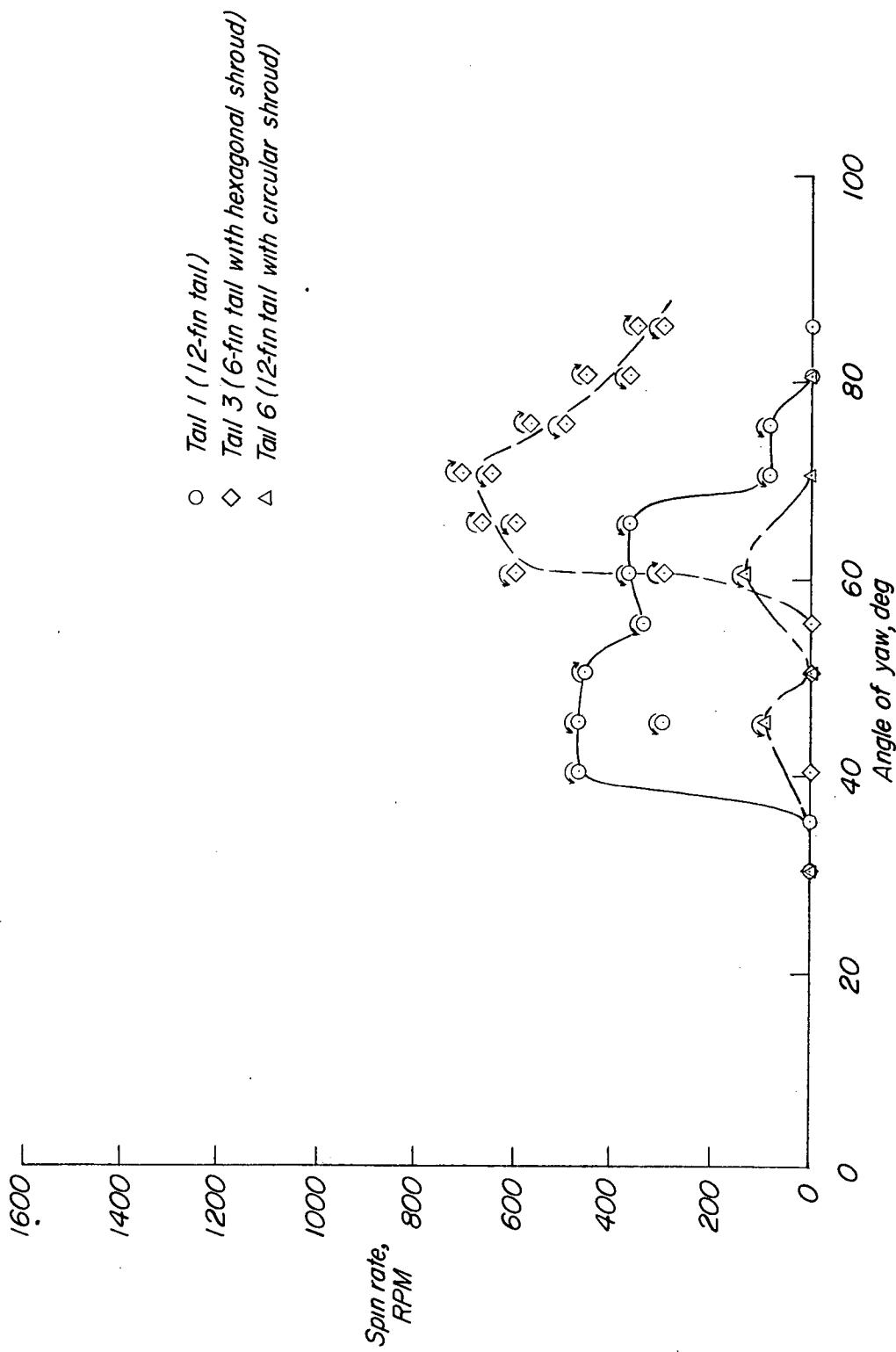


Figure 9.- Effect of shrouds on spin of mortar-shell tails. Direction of spin indicated by arrows (see fig. 2).

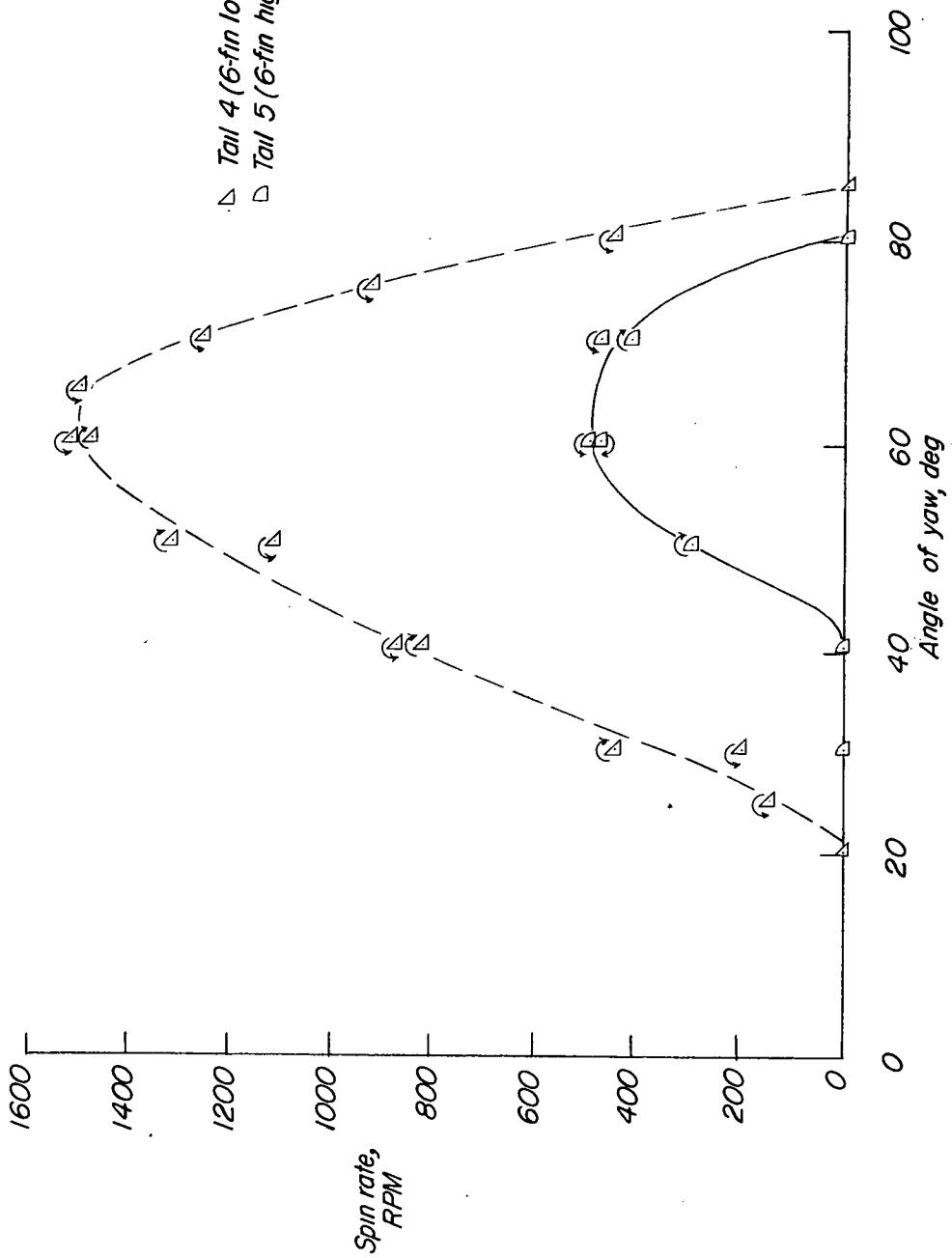


Figure 10.- Effect of aspect ratio on spin of mortar-shell tails. Direction of spin indicated by arrows (see fig. 2).

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